Evolution in Electrical and Electronic Engineering Vol. 4 No. 1 (2023) 389-397
© Universiti Tun Hussein Onn Malaysia Publisher's Office

EEEE

Homepage: http://publisher.uthm.edu.my/periodicals/index.php/eeee
e-ISSN : 2756-8458

Development of Smart Spirometer System for at-Home Post Covid-19 Patients

Iswerya Ramaiya[1], Nurmiza Othman[1]*

[1]Faculty of Electrical and Electronic Engineering,
Universiti Tun Hussein Onn Malaysia, 86400 Batu Pahat, Johor, MALAYSIA.

*Corresponding Author Designation

DOI: https://doi.org/10.30880/eeee.2023.04.01.046
Received 15 January 2023; Accepted 28 March 2023; Available online 30 April 2023

Abstract: This project proposes the development of a smart spirometer system for at-home use by post-Covid-19 patients in order to address the need for long-term monitoring of pulmonary function during rehabilitation. The system is composed of a TCRT5000 infrared sensor, a Node MCU ESP8266 microcontroller, a YFS-201 flow meter sensor, and a Liquid Crystal Display (LCD) unit. The TCRT5000 infrared sensor is small and lightweight and can detect the presence of a ball while, the YFS-201 flow meter sensor measures the volumetric flow of the respiration rate and sends the data in the form of voltage to the microcontroller. The microcontroller converts the voltage value into digital form and displays the output through the LCD 16x2 display and the Blynk application. With the data provided, important physiological parameters such as air flow rate, Q_{IO}, and volumetric flow, V can be calculated. The final outputs of the project are Tidal Volume and Inspiratory Capacity Volume (in liter). This smart spirometer system provides a low-cost and convenient method for monitoring pulmonary condition during recovery from Covid-19.

Keywords: Smart Spirometer, Internet Of Things (Iot), Post Covid-19 Monitoring, Respiratory System

1. Introduction

The severe acute respiratory syndrome Coronavirus 2 (SARS-CoV-2) causes the novel coronavirus illness, Covid-19 [1][2]. On March 11, 2020, the World Health Organization (WHO) classified the Covid-19 outbreak a pandemic, requiring comprehensive national and global mitigation measures, as well as a strong public health response and coordination across the globe.

In accordance with previous reports, viruses of the coronavirus family, including SARS-CoV2, mostly enter the human body through the mucosa of the nose and oropharynx, with some viruses finally becoming ensconced in the lungs [2]. It is possible that more air sacs will become filled with fluid because of the progression of Covid-19 pneumonia. This fluid is leaking from microscopic blood vessels in the lungs.

**Corresponding author: nurmiza@uthm.edu.my*

Most people who contract coronavirus disease 2019 (Covid-19) recover entirely within a few weeks after contracting the virus. However, some patients, even those who had minor forms of the disease, continue to experience symptoms after they have recovered from their initial illness [3]. These individuals have been referred to as "long haulers," and the conditions they are suffering from have been dubbed "post-Covid-19 syndrome" or "long Covid-19."

Spirometers are commonly used during physical therapy to assess lung capacity and chest responsiveness [4]. However, most available spirometers on the market are digital and expensive, making it unaffordable for many post-Covid patients. The current spirometers available on the market require installation of software and connection to a computer, which can be a difficult task. However, the newly built spirometer in this work is portable and stores findings in the cloud, making it convenient to access at any time [5]. In the context of the ongoing Covid-19 pandemic, this smart spirometer is especially useful for post-Covid patients to assess their lung efficiency at home, without the need to frequently visit healthcare facilities. This technology has the potential to decrease the number of patients admitted to hospitals and reduce wait times. Additionally, the smart spirometer is reasonably priced, making it accessible to people of all socioeconomic backgrounds, unlike the current expensive spirometers available on the market. Therefore, the development of a low-cost and IoT-enabled smart spirometer would allow patients to do at-home rehabilitation and evaluate their lung capacity, while also enabling remote monitoring by caregivers.

2. Methodology

2.1 Smart spirometer system

Figure 1 shows the overall flowchart of the developed smart spirometer system. The subject first inhales through the spirometer, causing the ball in the transducer connected to the tube to move. If the ball does not move, the subject should inhale again. Once the ball moves, the distance it moved is measured using an infrared sensor. This measurement is in the form of voltage, which is then converted to digital form by the Node MCU microcontroller's analog-to-digital conversion (ADC) pin. This digital data is sent to an application and displayed on an LCD screen and through the BLYNK application. The YFS-201 flow meter sensor also measures the flow rate of the respiratory signal and calculates the final output of the system, known as tidal volume and inspiratory capacity volumetric. This result is displayed on the BLYNK application and can be stored for up to 3 months for later monitoring by a physician or caretaker.

The system uses three compartments with different colored balls (red, orange, and green) to represent different volumes of air. By measuring the volume of air inspired over time, the system can evaluate lung function and diagnose respiratory conditions. The first measurement that the developed smart spirometer system measured is the air flow rate during the inhaling process, measured in liters per hour. It is the air passes through the flow meter sensor, which can be described as *QIO* (inflow and outflow). The *QIO* formula:

$$QIO = k * f \qquad \text{Eqn. (1)}$$

k is a constant value that is calculated by dividing the flow rate by the frequency of one rotation of the propeller, and f represents the frequency of one rotation of the propeller. The value of k is found to be 7.5. This formula is used to measure the air flow rate during inhalation, which is important in evaluating lung function and diagnosing respiratory conditions.

The system uses three compartments with different colored balls (red, orange, and green) to represent different volumes of air. By measuring the volume of air inspired over time, the system can evaluate lung function and diagnose respiratory conditions. The results of spirometry often include a graph showing the volume of air inspired over time. The system uses a time interval, Δt = 0.000833 hours, to calculate the final volumetric flow of air, where the formula is:

$$V=QIO*\Delta t \qquad \text{Eqn. (2)}$$

The volumetric flow, represented by V, is the amount of air (in liters) that flows into the lungs (or reservoir) of the dummy during a specific time interval, represented by Δt (in hour). The results obtained from this project can be classified into two distinct parameters: Tidal Volume (TV) and Inspiratory Reserve Volume (IRV). The TV measurement is taken before any physical activity, while the IRV measurement is taken after an exercise has been completed.

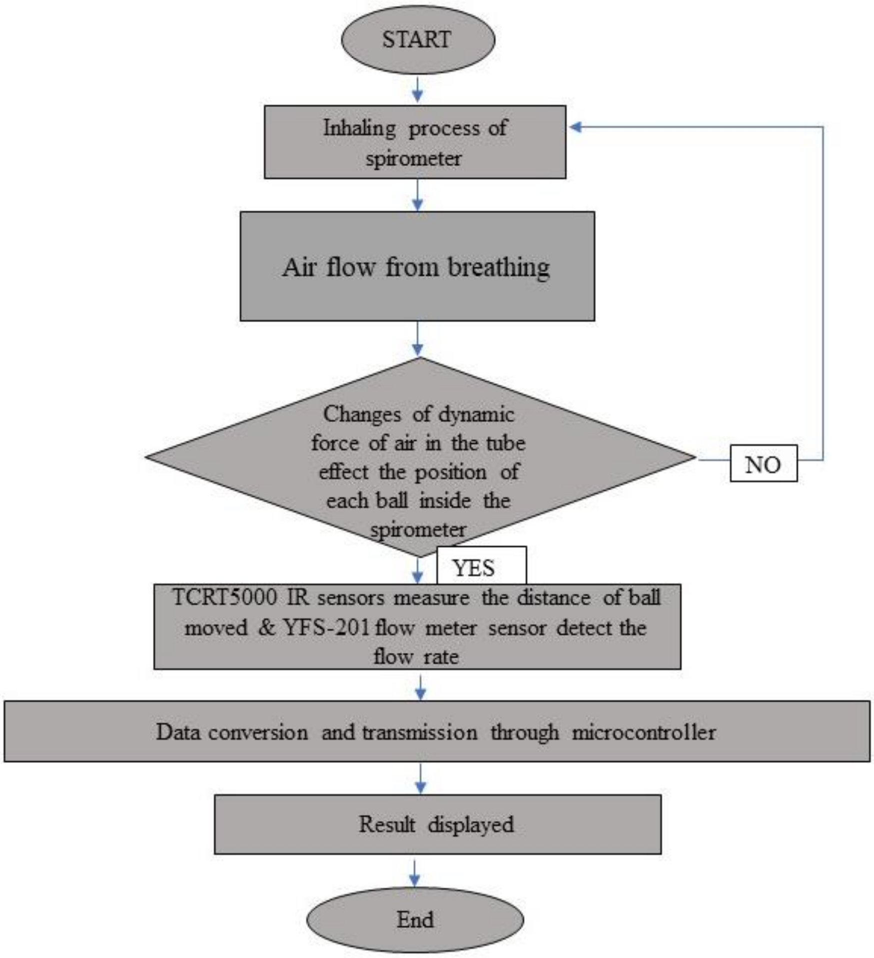


Figure 1: Operation of developed smart spirometer system

2.2 Materials and method

The smart spirometer system project can be divided into two main parts which are hardware and software development. The hardware development part consists of all the hardware components used in this project. Some of the components are three infrared sensor, microcontroller (Node MCU ESP 8266) [6], YFS-201 flow meter sensor [7], lithium ion/power supply [8], and LCD display 16 × 2 . The software development includes Proteus software to design the layout, Arduino IDE software [9]for the programming, and the Blynk application to connect as an IoT platform.

The developed smart spirometer system uses a disposable transducer that is designed using SolidWorks and 3D printing technology to maintain a high level of hygiene for patients undergoing functionality tests. The transducer is inserted into the tube during use and is immediately disposed of after the test is completed, ensuring a clean and hygienic experience for patients.

2.3 System functionality test

2.3.1 Test Procedure

Before beginning the test, the patient is instructed to sit comfortably near the device and to relax and take deep breaths to prepare for the test. They will then insert the disposable transducer of the spirometer into their mouth, and it is recommended that they perform a few normal breathing cycles before starting the examination.

The test involves taking three deep, slow exhales followed by rapid forced inhalations to inhale as much air as possible into the lungs. To ensure accurate results, it is advised that the patient avoid eating a large meal and refrain from smoking for five hours before the exam. After the initial reading is taken, the patient is instructed to perform a 1-minute-high knee raise exercise, and the test is conducted again to obtain results after exercise. Reading was taken before and after a quick activity done for rehabilitation purpose.

2.3.2 Volumetric flow range

The developed smart spirometer system is a device that measures the volume of air that is inhaled by the lungs, known as the tidal volume. It also measures the extra volume of air that can be taken in during inhalation beyond a normal tidal breath, known as the inspiratory reserve volume [10]. The system uses a flow meter sensor to measure the air flow rate during inhalation in litres per hour and calculates the volumetric flow of air using equations that involve the time interval (Δt), the volume of the compartments in cc per sec and the conversion factor between cc per sec to litres per hour. The equation can be express as:

$$1\ cc\ per\ \sec = 3.6\ liters\ per\ hour \qquad \text{Eqn. (3)}$$

The range of volumetric flow can be determined from the Eq. (3). The system also uses a Node MCU ESP8266 microcontroller and a real-time operating system to capture sensor data in real-time. The system uses three compartments with different coloured balls (red, orange, and green) to represent different volumes of air (600, 900 and 1200 cc per sec). By measuring the volume of air inspired over time, the system can evaluate lung function and diagnose respiratory conditions. The system uses a time interval, Δt = 0.000833 hours, to calculate the final volumetric flow of air.

3. Results and Discussion

The developed smart spirometer system is expected to achieve all the objectives and requirements needed. At the end of this project, a group of 5 subjects with different BMI, health status and gender were tested, and the data would be sent to the Blynk application. All the readings of the lung condition can be gained through this system where it will be easier for the caretaker to monitor their patient’s breathing rate.

3.1 System overview

The goal of this project was to create a sophisticated spirometer system, and this goal was successfully accomplished. The microcontroller played a vital role in controlling the airflow, while three TCRT 5000 Infrared Sensors were positioned on the spirometer to detect the presence of balls in each chamber. A YFS-201 flow meter sensor was also incorporated into the blowing tube to measure the air flow from the subject. The results were displayed on an LCD screen and could also be accessed through the BLYNK application, which had the capability to store the results for a period of three months, allowing caretakers to track the breathing level of their patients over time. Figure 2 shows the design of developed smart spirometer system.

The BLYNK application is a tool that utilizes IoT technology to remotely monitor the respiratory status of at-home Covid-19 patients. By using this application in conjunction with a smart spirometer system, healthcare providers can easily track changes in a patient's condition, identify worsening symptoms, and intervene before hospitalization becomes necessary. The continuous monitoring provided by this system also allows for a more comprehensive understanding of a patient's respiratory health, particularly for those with chronic conditions such as asthma or COPD. Additionally, the application is able to measure Tidal Volume and Inspiratory Reserve Volume which are important indicators of lung function. Overall, the integration of IoT technology in the development of smart spirometer system for at-home Covid-19 patients has the potential to improve patient care and outcomes, reduce the burden on the healthcare system, and provide more comprehensive monitoring of respiratory function.

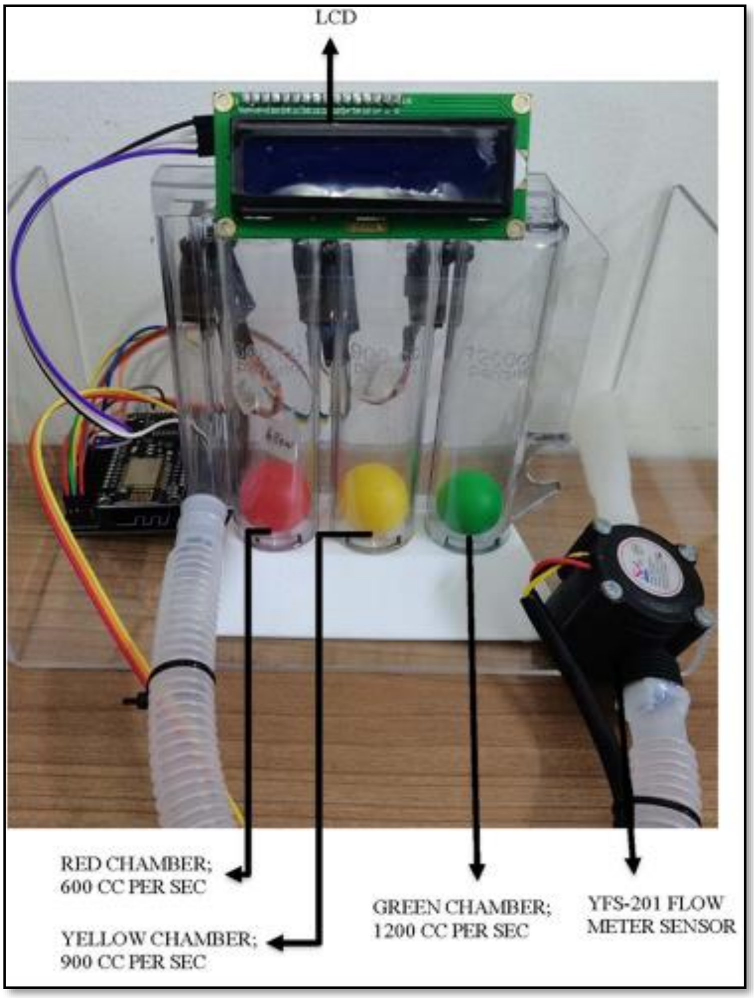


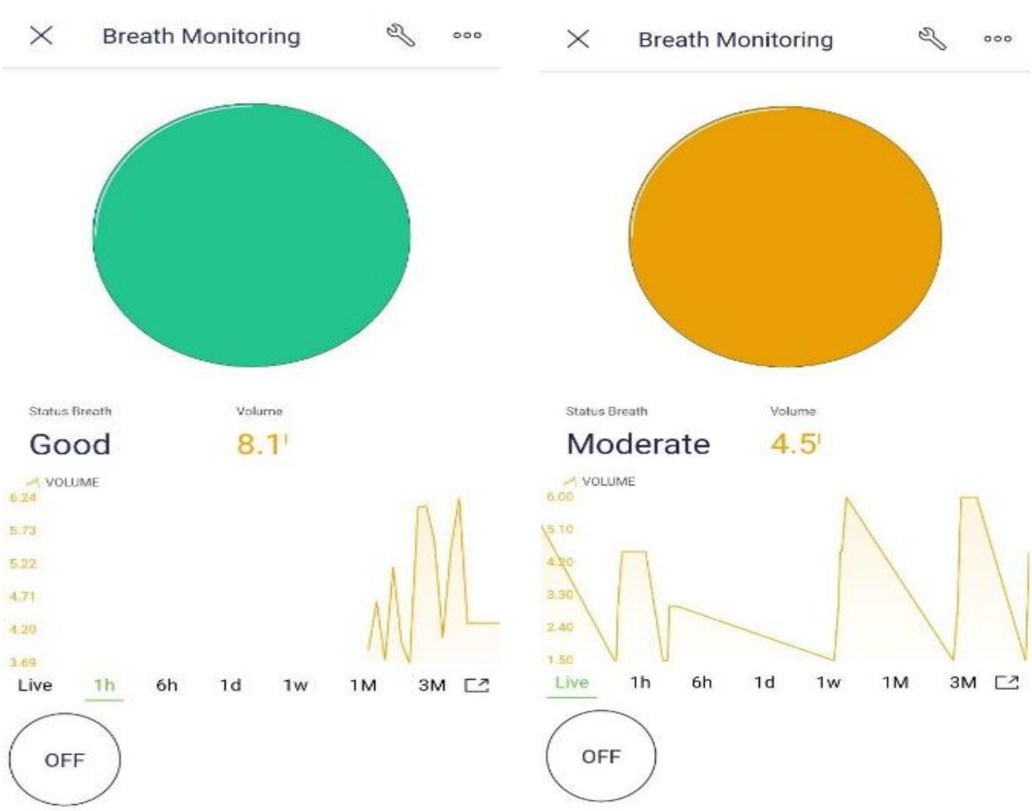
Figure 2: System front view

3.2 Functionality test of developed smart spirometer system

Reading was taken before and after a quick activity done for rehabilitation purpose. Figure 3(a) and Figure 4(a) show the result of subject ‘A’ before conducting an exercise and the result obtained in BLYNK application. Figure 3(b) shows the result of subject ‘A’ after conducting the exercise while Figure 4(b) is the related result obtained in BLYNK application.

(a) (b)

Figure 3: Testing results of the spirometer system for subject A (a) before, and (b) after conducting exercise



(a) (b)

Figure 4. Testing results viewed in BLYNK application for subject A (a) before, and (b) after conducting exercise

Functionality tests were undertaken among five subjects with different age, gender, BMI, and health status. Table 1 shows the result of functionality test of the five subjects before and after exercise. According to Eqn. (3) the volumetric flow range was determined and classified the state according. The average reading in the Table 1 calculated from sum of three reading readings divided by three. Then, it was classified according to the volumetric range and its related state.

Table 1: Result of Functionality Test of Smart Spirometer System

Subject	Age	Gender	Height (cm)	Weight (kg)	BMI (kg/m^2)	Health Status	Result (Liter, L)					
							Tidal Volume			Inspiratory Reserve Volume		
A	20	Male	183	59	17.6 Underweight	Post Covid Patient	8.1	7.9	8	4	4.5	4.3
							8 (Good)			4.27 (Moderate)		
B	24	Male	170	67	23.2 Normal	Post Covid Patient	6	7.5	8.1	3.6	3.6	4.1
							7.2 (Good)			3.77 (Moderate)		
C	22	Female	161	66.9	25.8 Overweight	Post Covid Patient	4.6	6	6.7	3	3.3	4.1
							5.77 (Good)			3.47 (Moderate)		
D	26	Male	172	64	21.6 Normal	Sinus Patient	7.5	7.5	8.1	6.7	7	7.1
							7.7 (Good)			6.93 (Good)		
E	23	Female	152	78.9	34.1 Obese Class I	Normal	2.1	2.7	3.2	1.7	1.67	1.7
							2.67 (Moderate)			1.69 (Bad)		

3.3 Comparison of Testing Results

Figure 5 shows the comparison of testing results obtained from the functionality test on different 5 subjects in the form of bar chart. From the bar chart result, it is obviously can see the reading of smart spirometer system tidal volume and inspiratory capacity volume. The Y-axis represent the Tidal Volume and Inspiratory Reserve Volume, while the X-axis represents five different subjects. Their inhaling spirometer readings were taken before and after exercise, with the following results: 8 liters before exercise and 4.27 liters after exercise for the first subject, 7.2 liters before exercise and 3.77 liters after exercise for the second subject, 5.77 liters before exercise and 3.47 liters after exercise for the third subject, 7.7 liters before exercise and 6.93 liters after exercise for the fourth subject and 2.67 liters before exercise and 1.69 liters after exercise for the fifth subject. All subjects showed a decrease in their inhaling spirometer reading after exercise, with subjects with lower BMI having higher reading before exercise and lower reading after exercise. The results indicate that the spirometer system is effective in measuring and improving respiratory function in post-COVID patients.

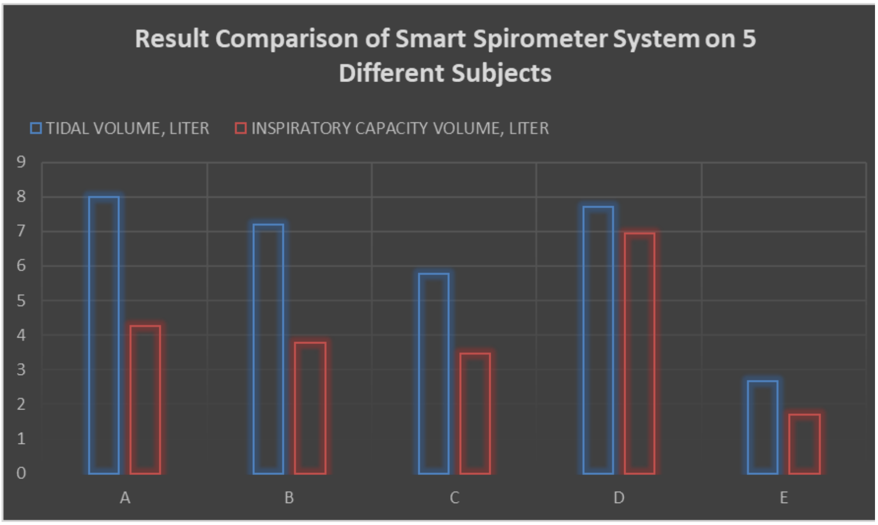


Figure 5: Result Comparison of Smart Spirometer System on 5 Different Subjects

3.4 Discussion

The subjects in Table 1 underwent a 1-minute-high knee jump exercise and their inhaling spirometer readings were taken before and after the exercise. As shows in Figure 5, the results of all subjects had decreased readings after the exercise, which is expected as muscles use more oxygen and produce more carbon dioxide during exercise. However, other factors such as daily routine, weather, and medical conditions may have also influenced the results. The subjects who were post-COVID-19 patients had lower readings compared to the subject with a sinus condition, potentially indicating the impact of COVID-19 on the respiratory system. Additionally, the subject with the highest BMI had the lowest reading after exercise, suggesting a potential correlation between BMI and the impact of exercise on lung function. Overall, the results suggest that a smart spirometer system can be useful for monitoring lung conditions during at-home rehabilitation activities.

4. Conclusion

As a conclusion, a spirometer system for at-home use was successfully designed and developed through this project. The system was designed to be compact and easy to use, with any necessary software or hardware components developed as needed. The spirometer system was integrated with IoT technology, allowing for remote monitoring by caregivers through the transmission of data to a remote server or device. The functionality of the spirometer was also tested on a group of post Covid-19 patients to assess its effectiveness in measuring and improving respiratory function. As a result, a reliable and effective tool for monitoring and improving respiratory function in post Covid-19 patients from the comfort of their own homes has been created, with the added convenience and peace of mind of remote monitoring for caregivers.

Acknowledgement

The authors would like to thank the Faculty of Electrical and Electronic Engineering, Universiti Tun Hussein Onn Malaysia for its support.

References

[1] WHO, “Update: 31 July 2020,” *Who*, no. July, pp. 1–203, 2020, [Online]. Available: https://www.who.int/emergencies/diseases/novel-coronavirus-2019/events-as-they-happen

[2] A. R. Bourgonje *et al.*, “Angiotensin-converting enzyme 2 (ACE2), SARS-CoV-2 and the pathophysiology of coronavirus disease 2019 (COVID-19),” *Journal of Pathology*, vol. 251, no. 3, pp. 228–248, 2020, doi: 10.1002/path.5471.

[3] W. H. ORGANIZATION, “Coronavirus disease (COVID- 19): Post COVID-19 condition,” no. December, pp. 1–2, 2021.

[4] CONTEC Medical, “Sp-10 pocket spirometer with bluetooth,” no. 112, pp. 1–32, 2018, [Online]. Available: http://www.contecmed.com/

[5] M. Khalili and R. J. Wong, “Underserved Does Not Mean Undeserved: Unfurling the HCV Care in the Safety Net,” *Dig Dis Sci*, vol. 63, no. 12, pp. 3250–3252, 2018, doi: 10.1007/s10620-018-5316-9.

[6] J. A. Hall, “NodeMCU ESP8266,” ウイルス, vol. 52, no. 1, pp. 1–5, 2002.

[7] Digi Key Electronics, “MODEL : YF-S201 Description : Features : Specifications : Application : Cercuit :,” *Https://Components101.Com/Diodes/Photodiode-Pinout-Datasheet*, p. 304, 2021.

[8] A. Yang, “Rechargeable Lithium Ion Battery Technology,” pp. 3–5, 2008.

[9] Arduino, "Arduino Integrated Development Environment (IDE) v1," *Arduino.CC*, pp. 1–16, 2022, [Online]. Available: https://docs.arduino.cc/software/ide-v1/tutorials/arduino-ide-v1-basics

[10] R. R. V. Leocádio, A. K. R. Segundo, and C. F. Louzada, "A sensor for spirometric feedback in ventilation maneuvers during cardiopulmonary resuscitation training," *Sensors (Switzerland)*, vol. 19, no. 23, 2019, doi: 10.3390/s19235095.